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Influence of cutting environments on surface integrity and power consumption of austenitic stainless steel

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ABSTRACT

Surface roughness is a result of the cutting parameters such as: cutting speed, feed per tooth and the axial depth of cut, also the tool's geometry, tool's wear vibrations, etc. Moreover, the surface finish influences mechanical properties such as fatigue behaviour, wear, corrosion, lubrication and electrical conductivity and the combination of cutting parameters influence the power consumption during the machining process affecting the environment. The research reported herein is focused mainly on searching for an optimum combination of cutting parameters to obtain a low value of surface roughness and minimize energy consumption when milling an austenitic stainless steel in different cutting environments. The experiments were conducted on a Siemens 840D Bridgeport Vertical Machining Centre 610XP2. The selection of this workpiece material was based on it's widely applications in cutlery, surgical instruments, industrial equipment and in the automotive and aerospace industry due to its high corrosion resistance and high strength characteristics. The results show that the dry cutting environment is the best option in terms of power consumption and surface roughness values to conduct the milling of an austenitic stainless steel under the selected cutting parameters.

1. Introduction

Metal machining processes generates heat due to tool friction, increasing tool wear and as a consequence reducing the tool life. Despite the fact that the use of cutting fluids benefits the cutting process as they remove heat more rapidly, some conventional cutting fluids are ineffective in controlling the high cutting temperature and the rapid tool wear as well as knowing how they deteriorate the environment. Due to the fact of pollution caused by cutting fluids in terms of recycling, disposal, works health issues, etc. the use of dry machining has increase in the workshops, however it can lead to reduce tool life and poor part quality. In order to avoid these problems flood-cooling methods can be used to enable efficient cutting of metals.

In order to lead to a conscious, clean and eco-friendly environment cryogenic cooling has showed great benefits as there is no need to recycle and/or disposal the cutting fluids. Based on the theory of cryogenic hardening, the field of cryogenics cutting (below -180 °C) advanced during the World War II when scientist found that besides contributing to an eco-environment, metals showed excellent wear resistance at frozen stage, better surface finish and improved tool life when comparing it to a dry cutting process The cooling process usually uses liquid nitrogen as is a fluid which can cause rapid freezing, it absorbs the heat from the cutting process and it becomes part of the air as it evaporates into nitrogen gas (79% of the air is composed by nitrogen). Other fluids commonly used are liquid helium and liquid CO_2 [1].

Researchers Hong and Broomer [2] conducted a cryogenic study when machining 304 stainless steel at $V=3.05-3.82$ m/s. They concluded that despites the benefits of an eco-friendly environment when using cryogenic machining, the liquid nitrogen produced an increased on the cutting forces and a reduced of tool life when machining this steel. However the process improved when injecting a small amount of liquid nitrogen to the chip-tool interface. In 2008 [3] compared the effects on tool life when using conventional cooling and cryogenic cooling when turning 304 stainless steel, where the results showed an increase of tool life of more than four times when using cryogenic cooling, also it was found to be more effective at higher cutting speeds.

Advantages of cryogenic machining over dry machining were also studied by [4]. In this case they studied the tool wear and the cutting forces generated during the cryogenic turning of 202 stainless steel. Their experiments showed an advantage of using cryogenic machining over dry machining as a decrease of 37% of the tool flank wear and 14.83% of the cutting forces were obtained.

In 2011 [5], studied the effect of cryogenic cooling when milling in different directions a 304 stainless steel. In their studies they

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did not observe an advantage of using cryogenic machining against dry machining as they obtained almost 8% of increase on the cutting forces when using cryogenic machining. Also it was highlighted that conventional milling yield the best results in terms of tool failure under both type of machining processes.

Bermingham et al. [6] studied the tool life, the cutting forces and the chip morphology when cryogenic turning titanium, Ti–6Al–4V. They concluded that a better tool performance was obtained when using cryogenic coolant and the main cutting forces decreased with this application. Also cryogenic coolant produced changes to the chip morphology and tool-chip contact length. Despite not having a significant effect on the chips thickness and the distance between serrations it appeared that this process has an effect on the tool-chip contact length and the primary shear band angle.

The influence of cryogenic cooling on surface integrity was studied by Umbrello et al. in 2012 [7]. In their studies an AISI 52100 steel was turned with cubic boron nitride tools with chamfered and horned geometries. The results showed that cryogenic machining offers a potential benefit for surface integrity (improved of the surface roughness) enhancement for improved product life.

Depending on materials mechanical, physical and chemical properties they are easier or more difficult to machine. The stainless steel has been defined as a difficult-to-machine ferrous alloy [8], basically due to its low thermal conductivity, where the heat generated during the cutting process concentrates in the cutting zone producing diffusion as main tool wear mechanisms as well as Built Up Edge (BUE) formation, this last increases the machining instability producing chipping on the cutting edge and poor surface quality.

With regards quantities of coolant, special attention should be given as a large amount can have a negative effect on the machinability and tool life by unfavourable cooling, which prevents heat softening of the workpiece material [9].

Based on all these reviews, the aim of this research is to study the optimal combination of cutting parameters for a low power consumption and low value of surface roughness when face milling a 303 austenitic stainless steel in different cutting environments such as: dry, flood coolant and cryogenic.

2. Experimental procedure

The importance in conducting this experiment is the contribution in the manufacturing field towards the eco-friendly machining of difficult-to-cut materials, through the application of different environments; as well as the possibilities of reducing power consumption and surface roughness based on an optimal combination of cutting parameters.

2.1. Workpiece material

303 Annealed stainless steel bars of 65 mm diameter and 120 mm length were pre-machined to $120 \times 55 \times 32$ mm^3 as shown in Fig. 1.

Tables 1 and 2 show the chemical composition and the mechanical properties of this 303 stainless steel respectively.

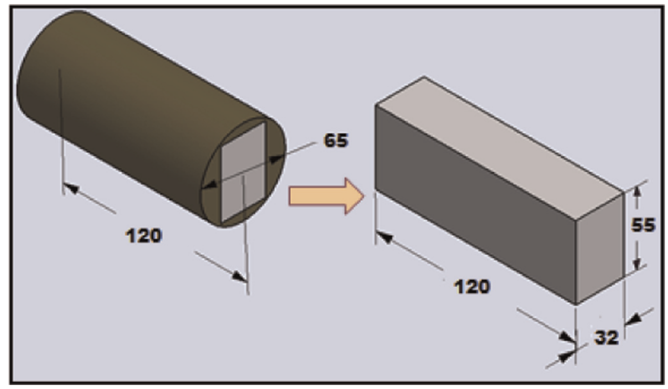

Fig. 1. Scheme of the workpiece geometry used in this study (units in mm).

Table 1
Chemical composition of 303 stainless steel bars used for the experiments.

%C	%Cr	%Fe	%Mn	%Mo	%Ni	%P	%Si	%S
<=0.15	18.0	69.0	<=2.0	<=0.6	9.0	<=0.2	<=1.0	>=0.15

Table 2
Mechanical properties 303 stainless steel bars used for the experiments.

BHN	σu (MPa)	σy (MPa)
160	620	240

2.2. Tool characteristics

A coated end mill and tool holder of $Ø_{Tool} = 14$ mm with 3 flutes was used for the climbing milling experiments, with the following code Guhring GTN 03872. This type of tool is recommended for the machining of stainless steel under different cutting environment. Fig. 2 shows a scheme of the tool geometry.

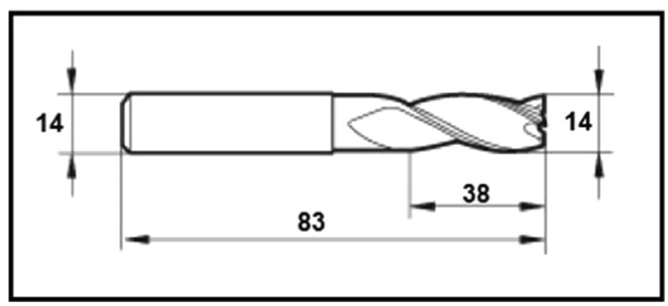

Fig. 2. Scheme of the tool geometry.

2.3. Cutting parameters and machining process

Dry, Flood Coolant and Cryogenic (liquid nitrogen) were selected as cutting environment and the cutting speed and feed per tooth were the cutting parameters chosen for the study, since from previous research it was observed that these variables had the most influence on the surface roughness. Selected cutting parameters are shown in Table 3.

Due to the restriction on the amount of material, the machining process was conducted based on the workpiece dimensions ($120 \times 55 \times 32$) and considering two trials per block, one in each side of the block. Five passes with $ae = 11$ mm were used to cover the width of the workpiece (55 mm). In order to guarantee that the vice was holding enough material, only a maximum depth of 18 mm could be reached, so three passes with $ap = 3$ mm each were used to cover a 9 mm depth for a trial on side A and 9 mm depth for the trial on side B. By taking into account these two factors the total length of cut is 1800 mm ($120 \times 5 \times 3$) per trial. Once side A was machined the block was turned over and a new setup of experiments was conducted for side B. Fig. 3 shows a scheme of the cutting process.